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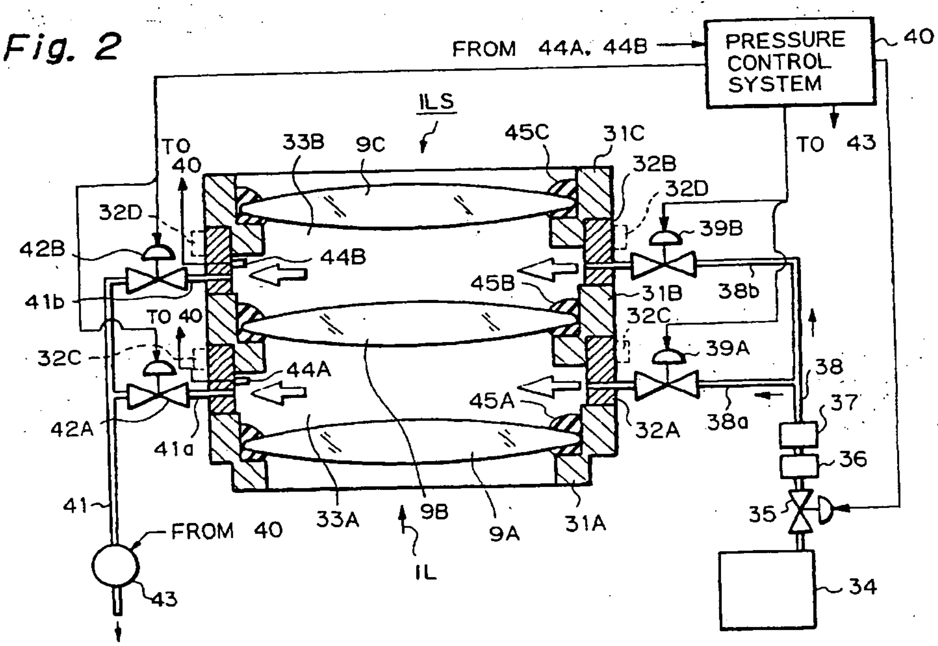
(54) Exposure apparatus

(57) In the exposure apparatus of the present invention, a sealed chamber defined by a first lens and a second lens in an input lens system on a plane of incidence of a fly-eye lens in an illumination optical system is provided. In a gas exchanging step, the impurity gas in the sealed chamber is first exhausted through an electromagnetic valve provided with a check valve and a gas exhaust pipe, using a gas exhaust pump and then, a high-purity nitrogen gas is supplied from a gas bomb through a gas supply pipe and an electromagnetic valve provided with a check valve to the sealed chamber. Using a pressure sensor provided in the sealed chamber, the gas exchanging step is repeated while maintaining an amount of change in pressure in the sealed chamber within a predetermined allowable range, to thereby reduce the concentration of impurities in the gas in the sealed chamber to a target value.

Fig. 2



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Description

The present invention relates to an exposure apparatus which is used for transferring a pattern on a mask to a substrate, such as a wafer, in a photolithography process for producing semiconductors, liquid crystal displays, thin-film magnetic heads, etc.

As exposure apparatuses used for producing, for example, semiconductors, there can be mentioned a projection exposure apparatus, such as a stepper, in which a reticle as a mask is illuminated with exposure light passing through an illumination optical system, to thereby transfer a pattern on the reticle through a projection optical system to a photoresist-coated wafer (or a glass plate), and an exposure apparatus of a proximity type or a contact type in which the pattern on the reticle is directly transferred to the wafer, using the above-mentioned exposure light. In these exposure apparatuses, ultraviolet light, such as an i-line from a super-high pressure mercury-vapor lamp (wavelength: 365 nm), has conventionally been used as exposure light.

In conventional exposure apparatuses, a series of lenses in the illumination optical system are divided into blocks and fixedly provided in lens barrels. In the illumination optical system, chambers defined by adjacent lenses are sealed by providing sealing materials between lenses and lens barrels. These sealing materials also serve as adhesives for fixing the lenses to the lens barrels. As such sealing materials, silicon-containing materials are generally used. In other words, in the sealed chambers in the illumination optical system, silicon-containing materials which serve not only as sealing materials, but also as adhesives are used. It is known that the sealing materials (or adhesives) containing silicon generate an organosilicon gas.

In conventional exposure apparatuses in which ultraviolet light is used as exposure light, ozone is produced from oxygen molecules in an atmosphere, in the presence of ultraviolet light. When an organosilicon gas is generated from the sealing materials (or adhesives) containing silicon, the ozone produced from oxygen in the presence of ultraviolet light oxidizes the organosilicon gas and consequently, deposition of haze substance, such as silicon dioxide (SiO_2), on the surfaces of lenses is likely to occur. This leads to a lowering of illuminance of exposure light and a non-uniform distribution with respect to illuminance of exposure light. Because low molecular weight siloxane contained in the sealing materials (or adhesives) is a cause of the generation of organosilicon gas, in order to prevent deposition of SiO_2 on the surfaces of lenses in an illumination optical system, recently, materials having a low content of low molecular weight siloxane have been used as the sealing materials (or adhesives).

Thus, in illumination optical systems in conventional exposure apparatuses, sealing materials (or adhesives) which are unlikely to generate an organosilicon gas, such as materials having a low content of low molecular weight siloxane, are used. However, such sealing materials exhibit poor operability due to a prolonged solidification time. Further, even when the content of low molecular weight siloxane in the sealing material is low, liberation of silicon cannot be completely suppressed, so that an organosilicon gas is generated in a small amount with a consequence that a small amount of SiO_2 is likely to be deposited on the surface of lens.

As another example of sealing materials which are unlikely to generate an organosilicon gas, there can be mentioned non-evaporative two-liquid type adhesives. However, such two-liquid type adhesives also have poor operability.

Recently, there has been an increasing tendency to use, as exposure light, excimer laser beams having a short wavelength, such as a KrF excimer laserbeam (wavelength: 248 nm) and an ArF excimer laser beam (wavelength: 193 nm). On the other hand, it is known that when light having a short wavelength, such as excimer laser beams, is irradiated to adhesives containing silicon, silicon is liberated in a large amount. Therefore, it is considered that when excimer laser beams are used as exposure light, deposition of haze substance on the surfaces of lenses occurs in a wide range in the illumination optical system, so that countermeasures for deposition of haze substance have been strongly desired.

In view of the above situation, the present invention has been made. It is a primary object of the present invention to provide an exposure apparatus in which deposition of haze substance on optical members, such as lenses, in an illumination optical system can be suppressed, to thereby prevent a lowering of light transmittance and light reflectance of the lenses.

According to the present invention, there is provided an exposure apparatus for illuminating a pattern on a mask with exposure light passing through an illumination optical system, to thereby transfer the pattern on the mask to a substrate, comprising:

> a sealed chamber provided in an optical path of the exposure light in the illumination optical system, the sealed chamber containing a gas and shielded from a gas surrounding the sealed chamber in the illumination optical system; and
> a gas exchanging device adapted to exchange the gas in the sealed chamber with a predetermined gas.

In the above-mentioned exposure apparatus, when an inert gas is contained in the sealed chamber, generation of ozone due to ultraviolet light which is used as exposure light can be avoided, so that even when an impurity gas, such as an organosilicon gas, is generated from sealing materials which are used in optical members (such as lenses) in contact with the gas in the sealed chamber, deposition of haze substance, such as SiO_2, on the surfaces of optical members can be prevented. Further, when the gas in the sealed chamber is

periodically exchanged with the predetermined gas, the impurity gas generated from the sealing materials can be removed. Due to the above two effects, occurrence of haze on the surfaces of optical members (leading to a lowering of light transmittance and light reflectance of the optical members) can be suppressed. As the inert gas contained in the sealed chamber, a high-purity nitrogen gas and a rare gas, such as helium, may be used.

In the above-mentioned exposure apparatus, it is preferred that the gas exchanging device comprise:

a gas exhausting system adapted to exhaust the gas in the sealed chamber;
a gas supplying system adapted to supply the predetermined gas to the sealed chamber;
a pressure sensor provided in the sealed chamber to detect a pressure in the sealed chamber; and
a control system adapted to control an operation of each of the gas exhausting system and the gas supplying system, based on the pressure in the sealed chamber detected by the pressure sensor, to thereby exchange the gas in the sealed chamber with the predetermined gas.

In the exposure apparatus having the gas exchanging device arranged as mentioned above, it is possible to exchange an impurity gas in the sealed chamber with an inert gas by repeating a gas exchanging operation in which a step of exhausting the impurity gas from the sealed chamber through the gas exhausting system and a step of supplying the inert gas through the gas supplying system to the sealed chamber are successively conducted.

In the present invention, it is more preferred that when the gas in the sealed chamber is exchanged with the predetermined gas, the control system enable the gas exhausting system to exhaust the gas in the sealed chamber and the gas supplying system to supply the predetermined gas to the sealed chamber, while maintaining an amount of change in the pressure in the sealed chamber detected by the pressure sensor within a predetermined allowable range. For example, an impurity gas in the sealed chamber may be exchanged with an inert gas by exhausting the impurity gas in an extremely small amount from the sealed chamber through the gas exhausting system and subsequently, supplying the inert gas in an amount equal to the amount of exhausted impurity gas through the gas supplying system to the sealed chamber so that a radical change in pressure in the sealed chamber can be suppressed. By this arrangement, stresses acting on lenses in contact with the gas in the sealed chamber become low, so that deterioration in performance of the illumination optical system can be avoided.

When the gas in the sealed chamber is exchanged with the predetermined gas with high frequency during assembly of the exposure apparatus, while suppressing a radical change in pressure in the sealed chamber, solidification of sealing materials (or adhesives) used in the lenses in contact with the gas in the sealed chamber is promoted, so that the time required for assembling the exposure apparatus can be reduced. In this case, because the gas exchange is conducted in a substantially stationary state with respect to the pressure in the sealed chamber, stresses acting on support members for supporting the lenses in contact with the gas in the sealed chamber are low and hence, damage to the lenses and deformation of the support members can be prevented. After operation of the exposure apparatus is started, it is preferred to exchange the gas in the sealed chamber periodically during idling of the exposure apparatus.

Further, in the present invention, it is preferred that the illumination optical system in the exposure apparatus comprise a light source adapted to emit exposure light, a shaping optical system adapted to shape the exposure light passing therethrough and an optical integrator adapted to enable the exposure light to have a uniform illuminance distribution after passing through the shaping optical system, and the sealed chamber be defined by two optical members constituting the shaping optical system. Because exposure light exhibits considerably high illuminance on a plane of incidence of the optical integrator, deposition of haze substance on the surfaces of lenses in the shaping optical system is likely to occur. However, by providing a sealed chamber defined by lenses in the shaping optical system and exchanging an impurity gas in the sealed chamber with a predetermined gas, the above-mentioned deposition of haze substance on the surfaces of lenses in the shaping optical system can be avoided.

Further, according to the present invention, there is provided a method for conducting an exchange of gases in a sealed chamber provided in an exposure apparatus, comprising a gas exchanging step including:

a first sub-step of exhausting a gas in the sealed chamber from a gas exhaust side thereof, while the sealed chamber is closed on a gas supply side thereof; and
a second sub-step of supplying an inert gas to the sealed chamber from the gas supply side thereof, while the sealed chamber is closed on the gas exhaust side thereof,
wherein each of the first sub-step and the second sub-step is conducted in a substantially stationary state with respect to a pressure of the gas in the sealed chamber.

Still further, according to the present invention, there is provided an exposure apparatus comprising:

an illumination optical system adapted to emit exposure light, the exposure light being adapted to illuminate a mask pattern to thereby transfer the mask pattern to a substrate;

a sealed chamber provided in the illumination optical system; and
a gas exchanging device adapted to exhaust a gas in the sealed chamber and supply an inert gas to the sealed chamber.

Still further, according to the present invention, there is provided a projection exposure apparatus for transferring a pattern on a mask to a photosensitive substrate, comprising:

a light source adapted to emit exposure light having a wavelength range in which a photosensitive substrate is sensitive to the exposure light;
an illumination optical system provided between the light source and the mask;
a projection optical system provided between the mask and the photosensitive substrate;
a sealed chamber containing a gas and provided in an optical path of the exposure light between the light source and the photosensitive substrate; and
a gas circulating device connected to the sealed chamber,
the gas circulating device being adapted to exhaust the gas contained in the sealed chamber to an outside thereof, to thereby compensate for variations in intensity of the exposure light on the photosensitive substrate.

Still further, according to the present invention, there is provided a projection exposure apparatus for transferring a pattern on a mask to a photosensitive substrate, comprising:

a light source adapted to emit exposure light having a wavelength range in which a photosensitive substrate is sensitive to the exposure light;
a sealed chamber provided in an optical path of the exposure light between the light source and the photosensitive substrate; and
a gas circulating device having a sensor and connected to the sealed chamber,
the sensor being adapted to detect and output information corresponding to a pressure in the sealed chamber, and
the gas circulating device being adapted to supply an inert gas to the sealed chamber in accordance with the information outputted from the sensor.

Still further, according to the present invention, there is provided a method for transferring a pattern on a mask to a photosensitive substrate, comprising the steps of:

illuminating the mask with exposure light, to thereby transfer the pattern on the mask to a photosensitive substrate; and
exchanging an inert gas contained in a sealed chamber with another gas,
the sealed chamber being provided in an optical path of the exposure light,
to thereby compensate for variations in light transmittance and light reflectance of an optical member provided in the optical path of the exposure light.

Still further, according to the present invention, there is provided an exposure apparatus for transferring a pattern on a mask to a photosensitive substrate, comprising:

an optical system adapted to allow exposure light to enter,
said exposure light being adapted to be irradiated to a photosensitive substrate; and
a device adapted to supply a gas capable of suppressing attenuation of said exposure light to said optical system, according to a change in light transmittance of said optical system which occurs due to entrance of said exposure light.

Still further, according to the present invention, there is provided a method for making an apparatus for transferring a pattern on a mask to a photosensitive substrate, comprising the steps of:

providing an optical system between a light source and a photosensitive substrate,
said light source being adapted to emit exposure light,
said exposure light being adapted to enter said optical system and irradiate said photosensitive substrate; and
providing a device adapted to supply a gas capable of suppressing attenuation of said exposure light to said optical system, according to a change in light transmittance of said optical system.

The foregoing and other objects, features and advantages of the present invention will be apparent from the following detailed description and appended claims taken in connection with the accompanying drawings.

Fig. 1 is a perspective view of a partially cut-away exposure apparatus according to one embodiment of the present invention.
Fig. 2 is a cross-sectional view of a construction including an input lens system ILS and a gas exchange mechanism in the exposure apparatus of Fig. 1.
Fig. 3 is a graph showing one example of a change in pressure in the first sealed chamber 33A shown in Fig. 2 where a gas exchanging step is repeatedly conducted.
Fig. 4 is a graph showing a relationship between the number of times the gas exchanging step is conducted and the concentration of impurity gas, with

respect to the first sealed chamber 33A in Fig. 2 where the gas exchanging step is repeatedly conducted.

Hereinbelow, an exposure apparatus according to an embodiment of the present invention is explained, with reference to the drawings.

Fig. 1 shows a projection exposure apparatus as an exposure apparatus according to an embodiment of the present invention. In Fig. 1, illumination light IL1 from exposure light source 1 comprising a super-high pressure mercury-vapor lamp is collected by an elliptic mirror 2 and reflected by a mirror 3 and a mirror 4 toward a shutter 5. The shutter 5 is rotated by a drive motor 6, thereby opening and closing a passage for the illumination light IL1. When the shutter 5 is in an open state, the illumination light IL1 passes through the shutter 5, and illumination light exclusive of an i-line is removed by an interference filter 7. The i-line which has passed through the interference filter 7 constitutes exposure light IL and is reflected by a mirror 8 disposed so as to bend an optical path of the exposure light IL. The exposure light IL then passes through an input lens system ILS comprising a first lens 9A, a second lens 9B and a third lens 9C, and enters a fly-eye lens 10 in the form of a substantially parallel beam. Incidentally, as the exposure light IL, an h-line (wavelength: 405 nm) or a g-line (wavelength: 436 nm) may be used, instead of the i-line. An excimer laser beam, such as a KrF excimer laser beam and an ArF excimer laser beam, an F_2 laser beam (wavelength: 157 nm) or a harmonic component of a YAG laser beam, may also be used as the exposure light IL.

An aperture stop plate 11 for an illumination system is rotatably provided on a plane of exit of the fly-eye lens 10. The aperture stop plate 11 includes a normal circular aperture stop 13A, an aperture stop 13B for a modified light source, which comprises a plurality of small eccentric apertures, an annular stop 13C and the like. These aperture stops are formed around a rotation shaft of the aperture stop plate 11. A desired aperture stop for an illumination system can be disposed on the plane of exit of the fly-eye lens 10 by rotating the aperture stop plate 11 using a drive motor 12. A part of the exposure light IL which has passed through the desired aperture stop on the plane of exit of the fly-eye lens 10 is reflected by a beam splitter 14 and enters an integrator sensor 16 comprising a photoelectric conversion device through a collective lens 15. Illuminance of the exposure light IL on a wafer W can be indirectly monitored, based on a detection signal supplied from the integrator sensor 16.

On the other hand, the exposure light IL which has passed through the beam splitter 14 passes through a first relay lens 17A, a projection type reticle blind (variable field stop) 18, a second relay lens 17B, a mirror 19 disposed so as to bend the optical path of the exposure light IL and a condenser lens 20, and illuminates a reticle R. Thus, an illumination optical system is constituted by the exposure light source 1, the condenser lens 20 and the elements 2 to 19 provided between the exposure light source 1 and the condenser lens 20. Using the exposure light IL passing through this illumination optical system, an image of a pattern 21 on the reticle R is projected through a projection optical system PL to the photoresist-coated wafer W.

In Fig. 1, a Z-axis is taken in a direction parallel to an optical axis AX of the projection optical system PL and a coordinate system defined by an X-axis and a Y-axis which is perpendicular to the X-axis is contained in a plane perpendicular to the Z-axis. The reticle R is held on a reticle stage 28 which is adapted to perform alignment of the reticle R in an X direction, a Y direction and a rotation direction. The wafer W is held on a wafer holder 22 by suction. The wafer holder 22 is fixedly provided on a wafer stage 23. The wafer stage 23 is adapted to adjust the position of the wafer W along the Z-axis and a tilt angle of the wafer W so that the surface of the wafer W coincides with an image plane of the projection optical system PL. The wafer stage 23 is also adapted to perform stepping of the wafer W in the X direction and the Y direction and alignment of the wafer W. After exposure of one shot area on the wafer W is finished, stepping of the wafer stage 23 is conducted to thereby move another shot area on the wafer W which is subsequently subjected to exposure to an exposure field of the projection optical system PL, and exposure is conducted. Exposure is repeatedly conducted in a manner such as mentioned above by a so-called step-and-repeat exposure method, to thereby conduct exposure of a plurality of shot areas on the wafer W.

In the projection exposure apparatus in this embodiment of the present invention, ultraviolet light is used as the exposure light IL. Therefore, ozone is produced, in the presence of the exposure light IL, from oxygen within ambient air. The ozone thus produced oxidizes an organosilicon gas generated from sealing materials (or adhesives) used in optical members, such as lenses and mirrors, and deposition of haze substance, such as silicon dioxide (SiO_2), on the surfaces of optical members is likely to occur. In the present invention, in order to prevent such deposition of haze substance, a sealed chamber is provided in the optical path of the exposure light IL in the illumination optical system and a gas in the sealed chamber is exchanged with a predetermined gas. In the illumination optical system, the illuminance of the exposure light IL is especially high in the optical path from the exposure light source 1 to the fly-eye lens 10 as an optical integrator. In this embodiment, the sealed chamber is defined by adjacent lenses constituting the input lens system ILS which is provided on the plane of incidence of the fly-eye lens 10.

Fig. 2 shows a construction including the input lens system ILS and a gas exchange mechanism for the input lens system ILS. In Fig. 2, the first lens 9A, the second lens 9B and the third lens 9C are successively provided along the optical path of the exposure light IL. The first lens 9A is fixed to a ring-shaped first lens barrel 31A

with a sealing material 45A being provided therebetween. A second lens barrel 31B is disposed on a ring-shaped spacer 32A above the first lens barrel 31A. The second lens 9B is fixed to the second lens barrel 31B with a sealing material 45B being provided therebetween. A third lens barrel 31C is disposed on a spacer 32B above the second lens barrel 31B. The third lens 9C is fixed to the third lens barrel 31C with a sealing material 45C being provided therebetween. Each of the sealing materials 45A to 45C contains silicon and also serves as an adhesive. In this embodiment, two sealed chambers, namely, a first sealed chamber 33A and a second sealed chamber 33B are provided in the input lens system ILS. The first sealed chamber 33A is defined by the lenses 9A and 9B, the lens barrels 31A and 31B and the spacer 32A and shielded from a gas surrounding the first sealed chamber 33A. The second sealed chamber 33B is defined by the lenses 9B and 9C, the lens barrels 31B and 31C and the spacer 32B and shielded from a gas surrounding the second sealed chamber 33B. The lens barrels 31A to 31C and the spacers 32A and 32B are firmly fixed so as not to allow the lenses 9A to 9C to be displaced due to a change in atmospheric pressure. Further, in order to maintain the temperature of a gas in each of the sealed chambers 33A and 33B at a predetermined level, pipes 32C and 32D, each of which allows a fluid having a temperature controlled to a predetermined level to pass therethrough, are disposed on respective outer surfaces of the spacers 32A and 32B.

A gas bomb 34 in which a high-purity nitrogen gas as an inert gas is sealably contained under high pressure is provided outside a chamber accommodating the projection exposure apparatus. The high-purity nitrogen gas in the gas bomb 34 is supplied through an electromagnetic valve 35, a chemical filter 36 and an HEPA filter (high efficiency particulate air-filter) 37 to a gas supply pipe 38. The opening and closing of the electromagnetic valve 35 is controlled by a pressure control system 40 comprising a computer. A first pipe 38a branched from the gas supply pipe 38 is connected to the first sealed chamber 33A through an electromagnetic valve 39A provided with a check valve. A second pipe 38b branched from the gas supply pipe 38 is connected to the second sealed chamber 33B through an electromagnetic valve 39B provided with a check valve. The opening and closing of each of the electromagnetic valves 39A and 39B is also controlled by the pressure control system 40.

Further, the first sealed chamber 33A is connected to a gas exhaust pipe 41 through a first pipe 41a for gas exhaustion and an electromagnetic valve 42A provided with a check valve. The second sealed chamber 33B is connected to the gas exhaust pipe 41 through a second pipe 41b for gas exhaustion and an electromagnetic valve 42B provided with a check valve. The gas exhaust pipe 41 opens to the atmosphere outside the chamber accommodating the projection exposure apparatus through a gas exhaust pump 43 and a filter device (not shown). The opening and closing of each of the electromagnetic valves 42A and 42B and the operation of the gas exhaust pump 43 are controlled by the pressure control system 40. Pressure sensors 44A and 44B are provided in the sealed chambers 33A and 33B, respectively, so as to detect pressures in the sealed chambers 33A and 33B. Detection signals are supplied from the pressure sensors 44A and 44B to the pressure control system 40. Thus, the pressure control system 40 monitors respective pressures of gasses in the sealed chambers 33A and 33B, based on the detection signals from the pressure sensors 44A and 44B.

Basically, the gas exchange mechanism shown in Fig. 2 is operated as follows. Initially, while the electromagnetic valves 39A and 39B on a gas supply side are closed, the pressure control system 40 opens the electromagnetic valves 42A and 42B on a gas exhaust side, and actuates the gas exhaust pump 43 so that a part of the gas in the first sealed chamber 33A, that is, remaining oxygen and an impurity gas, such as an organosilicon gas generated from the sealing materials 45A and 45B, and a part of the gas in the second sealed chamber 33B, that is, remaining oxygen and an impurity gas, such as an organosilicon gas generated from the sealing materials 45B and 45C, are exhausted. Subsequently, the pressure control system 40 closes the electromagnetic valves 42A and 42B on the gas exhaust side and opens the electromagnetic valves 39A and 39B on the gas supply side, and also opens the electromagnetic valve 35, to thereby supply the high-purity nitrogen gas from the gas bomb 34 through the gas supply pipe 38 to each of the sealed chambers 33A and 33B. The pressure control system 40 ensures that the gas exchange is conducted in a substantially stationary state so that no radical changes occur with respect to the pressures of gases in the sealed chambers 33A and 33B, which pressures are detected by the pressure sensors 44A and 44B, respectively. Thus, the respective amounts of oxygen and the impurity gas (such as an organosilicon gas generated from the sealing materials) in each of the sealed chambers 33A and 33B decrease, so that the respective concentrations of oxygen and impurities in the gas in each of the sealed chambers 33A and 33B become low and hence, a process of deposition of haze substance on each of the lenses 9A to 9C is interrupted, to thereby prevent occurrence of haze on the surfaces of these lenses.

In this embodiment, the electromagnetic valves 39A, 39B, 42A and 42B, each provided with a check valve, are employed. Therefore, the gasses in the sealed chambers 33A and 33B flow in a single direction from the gas bomb 34 toward the gas exhaust pump 43 without occurrence of a reverse gas flow. Therefore, the impurity gas in each of the sealed chambers 33A and 33B can be efficiently exchanged with the high-purity nitrogen gas.

Next, referring to Figs. 1 to 4, explanation is made

on one example of an operation for conducting an exchange of gases in the first sealed chamber 33A in a substantially stationary state using the gas exchange mechanism shown in Fig. 2. This operation is mainly conducted during idling of the projection exposure apparatus between exposure operations.

When the pressure P of the gas in the first sealed chamber 33A at a time point t_o when an exchange of gases is started is indicated as an initial value P_0, this initial value P_0 is substantially equal to the pressure of a gas surrounding the illumination optical system (1 atm in this embodiment). At the time point t_o, the electromagnetic valve 42A on the gas exhaust side is opened while the electromagnetic valve 39A on the gas supply side is closed, and the gas exhaust pump 43 is actuated so as to exhaust the gas in the first sealed chamber 33A until the pressure P of the gas in the first sealed chamber 33A, which is detected by the pressure sensor 44A, decreases by an amount Δp which is within a predetermined allowable range. The time period between the time point to and the time point when the pressure P decreases by the allowable amount Δp is indicated as Δt_1.

Fig. 3 is a graph showing one example of a change in pressure in the first sealed chamber 33A shown in Fig. 2 where the exchange of gases is conducted. In the graph of Fig. 3, the change in the pressure P in the first sealed chamber 33A is indicated by a solid curved line 51. In Fig. 3, the abscissa indicates the time t and the ordinate indicates the pressure P. In Fig. 3, the pressure P decreases by the allowable amount Δp from the initial value P_0 at a time point t_1. Therefore, in Fig. 3, the above-mentioned time period Δt_1 is indicated as the time period between the time point t_o and the time point t_1.

Subsequently, the electromagnetic valve 42A on the gas exhaust side is closed and the electromagnetic valve 39A on the gas supply side is opened. The electromagnetic valve 35 is also opened, to thereby supply the high-purity nitrogen gas from the gas bomb 34 to the first sealed chamber 33A. In this instance, using the pressure sensor 44A, the high-purity nitrogen gas is supplied until the pressure P in the first sealed chamber 33A is recovered to the initial value P_0. As indicated by the solid curved line 51 in Fig. 3, the pressure P is recovered to the initial value P_0 at a time point t_2. The time period between the time point t_1 and the time point t_2 is indicated as Δt_2. Thereafter, the above-mentioned operation (hereinafter, frequently referred to simply as "gas exchanging step") comprising a step of exhausting the gas in the first sealed chamber 33A until the pressure P of the gas in the first sealed chamber 33A decreases by the allowable amount Ap from the initial value P_0 (first sub-step) and a step of supplying the high-purity nitrogen gas to the first sealed chamber 33A until the pressure P is recovered to the initial value P_0 (second sub-step) is repeated. When the gas exchanging step is repeated, the solid curved line 51 which indicates the change in the pressure P exhibits a sine waveform.

Fig. 4 is a graph showing a relationship between the number n of times the gas exchanging step is conducted and the concentration C of impurity gas, with respect to the first sealed chamber 33A in Fig. 2 where the gas exchanging step is repeatedly conducted. The graph of Fig. 4 is obtained in a manner as mentioned below. When the amount of gas in the first sealed chamber 33A which is exchanged at each gas exchanging step (hereinafter, frequently referred to simply as "gas exchange amount") is indicated as Δq, the value of Δq is determined in accordance with the above-mentioned allowable amount Δp. Further, when the internal volume of the first sealed chamber 33A is indicated as Q and the concentration of impurity gas (such as an organosilicon gas) in the gas in the first sealed chamber 33A after the gas exchanging step is conducted at i time(s) (i = 1, 2, ...) is indicated as C_i, because gases become mixed at a sufficiently high rate, the concentration C_{i+1} of impurity gas after the gas exchanging step is conducted (i + 1) times is determined in accordance with the following formula (1).

$$C_{i+1} = C_i\,(1 - \Delta q/Q) \tag{1}$$

From this formula (1), the concentration C_i of impurity gas is indicated by the following formula (2), using the concentration C_1 of impurity gas after the gas exchanging step is conducted at one time.

$$C_i = C_1\,(1 - \Delta q/Q)^{i-1} \tag{2}$$

When a target value of the concentration C of impurity gas is indicated as C_L, the following formula (3) is obtained from the formula (2), with respect to the number N of times the gas exchanging step needs to be conducted for achieving the target value C_L.

$$C_N = C_i\,(1 - \Delta q/Q)^{N-1} \leqq C_L \tag{3}$$

Accordingly, with respect to the number n (n = 1, 2 ..., N) of times the gas exchanging step is conducted, the concentration C of impurity gas in the gas in the first sealed chamber 33A changes as indicated by a solid curved line 52 in the graph of Fig. 4. On the other hand, the formula (3) can be reformulated as follows.

$$(1 - \Delta q/Q)^{N-1} \leqq C_L/C_1 \tag{4A}$$

$$(N - 1) \log (1 - \Delta q/Q) \leqq \log (C_L/C_1) \tag{4B}$$

With respect to the formula (4B), $\log (1 - \Delta q/Q) < 0$ and $\log (C_L/C_1) < 0$. Therefore, the formula (4B) can be

reformulated as follows.

$$(N - 1) \geqq \log (C_L/C_1)/\log (1 - \Delta q/Q) \qquad (4C)$$

$$N \geqq 1 + \log (C_L/C_1)/\log (1 - \Delta q/Q) \qquad (4D)$$

Therefore, when the internal volume Q of the first sealed chamber 33A, an appropriate gas exchange amount Δq (or the allowable amount Δp of change in pressure of the gas in the first sealed chamber 33A), the concentration C_1 of impurity gas after the gas exchanging step is conducted at one time and the target value C_L of the concentration C of impurity gas are determined, the minimum value N_{min} of the number N of times the gas exchanging step needs to be conducted for suppressing the concentration C of impurity gas to the target value C_L or less can be determined, in accordance with the formula (4D). In this embodiment, the number of times the gas exchanging step is conducted is N_{min} which is the minimum value of the integer N satisfying the formula (4D). Thus, the concentration C of impurity gas can be suppressed to the target value C_L or less by conducting the gas exchanging step at N_{min} time(s).

With respect to the gas exchange amount Δq (or the allowable amount Δp of change in pressure of the gas in the first sealed chamber 33A), when the gas exchange amount Aq is too large, stresses acting on the lenses, such as the first lens 9A in Fig. 2, become high, so that problems arise, such as displacement, a change in aberration, damage and breakage of lenses. Even when damage or breakage of lenses is avoided, a substantial amount of stress is likely to have an adverse effect on the aberration of lenses which has already been corrected. Therefore, in this embodiment of the present invention, the gas exchange amount Δq (or the allowable amount Δp of change in pressure of the gas in the first sealed chamber 33A) is suppressed to a level such that the pressure in the first sealed chamber 33A changes in a substantially stationary state. For example, the allowable amount Δp is determined as being an amount several times the amount which is capable of being detected by the pressure sensor 44A in the first sealed chamber 33A in Fig. 2, and the gas exchange amount Δq is determined from the thus determined amount Δp. By this arrangement, an undesirable increase in stress acting on lenses during the exchange of gases in the first sealed chamber 33A can be prevented and the above-mentioned problems accompanying the exchange of gases, such as a change in aberration of lenses, can be suppressed within a sufficiently narrow allowable range.

When the minimum value N_{min} of the number N of times the gas exchanging step is conducted, which is determined in accordance with the formula (4D), becomes large so that a total gas exchange time [i.e., the time period during which the gas exchanging step is conducted at N_{min} time(s)] exceeds an idling time of the projection exposure apparatus, a time for conducting the gas exchanging step at one time may be reduced by reducing the time period t_1 and the time period t_2 in Fig. 3. With respect to the second sealed chamber 33B in Fig. 2, the impurity gas in the second sealed chamber 33B is exchanged with the inert gas in substantially the same manner as in the first sealed chamber 33A, while suppressing a change in aberration of lenses and the like.

Preferably, the above-mentioned gas exchanging step is conducted periodically during idling of the projection exposure apparatus, because an organosilicon gas is gradually generated from the sealing materials 45A to 45C in Fig. 2. By this arrangement, gradual deposition of haze substance on the surfaces of lenses can be prevented.

Although the gas exchanging step is conducted during idling of the projection exposure apparatus in the above-mentioned embodiment, in the present invention, the gas exchanging step may be conducted during assembly and adjustment of the projection exposure apparatus in a manner as mentioned below. That is, immediately after the lenses 9A to 9C are fixed to the lens barrels 31A to 31C with the sealing materials 45A to 45C being provided therebetween, the gas in each of the sealed chambers 33A and 33B may be exchanged with a high-purity nitrogen gas through the gas exchange mechanism in Fig. 2, while maintaining an amount of change in pressure in each of the sealed chambers 33A and 33B at Δp or less. In this instance, because the amount of change in pressure during the gas exchanging step is as small as Δp or less, it is unnecessary to wait until the sealing materials 45A to 45C are completely solidified. Further, because the organosilicon gas generated from the sealing materials 45A to 45C during solidification thereof is efficiently exhausted through the gas exhaust pump 43, the solidification time can be reduced and the time for assembly can also be reduced. Further, there is no phenomenon such that organosilicon substance adheres to and remains on the surfaces of the lenses 9A to 9C and the inner walls of the lens barrels 31A and 31C. Thus, deposition of haze substance on the lenses 9A to 9C can be completely prevented.

In the above-mentioned embodiment, when moisture remains in the gas supply pipe 38 in Fig. 2, such moisture enters the sealed chambers 33A and 33B, in accordance with the flow of gas supplied to the sealed chambers 33A and 33B. In this case, not only does a lowering of efficiency in exhausting impurities occur, but also the moisture react with coating materials on lenses in an early stage and the resultant reaction product is likely to be deposited on the surfaces of lenses, thereby contaminating the lenses. Therefore, it is preferred to provide the gas supply pipe 38 with another exhaust port and preliminarily clean the gas supply pipe 38 by flowing

an inert gas, such as a nitrogen gas (N_2) and helium (He), from this exhaust port through the gas supply pipe 38.

In the above-mentioned embodiment, the gas exchange mechanism is provided in the input lens system ILS in Fig. 1. However, in the present invention, the gas exchange mechanism may also be applied to, for example, the interference filter 7, the fly-eye lens 10, the beam splitter 14, the relay lenses 17A and 17B in the illumination optical system, in order to prevent deposition of haze substance on these optical members. Further, when two fly-eye lenses 10 are provided so as to improve uniformity of illuminance distribution of exposure light and a relay lens system is provided between these two fly-eye lenses, the gas exchange mechanism may be provided in this relay lens system.

Further, as the inert gas used in the gas exchange mechanism, a high-purity nitrogen gas is employed in the above-mentioned embodiment. However, in the present invention, a chemically stable gas, for example, a rare gas, such as helium or hydrogen, may also be used as the inert gas. In an exposure apparatus in which a KrF excimer laser is used, dried air which is chemically clean may be used as the inert gas. The above-mentioned dried air is obtained by passing air through a chemical filter and adjusting the humidity of the filtered air to, for example, about 5% or less. With respect to the gas bomb 34 connected through the gas supply pipe 38 to the electromagnetic valves 39A and 39B on the gas supply side and the gas exhaust pump 43 connected through the gas exhaust pipe 41 to the electromagnetic valves 42A and 42B on the gas exhaust side in Fig. 2, the gas bomb 34 and the gas exhaust pump 43 may be temporarily connected only when the gas exchanging step is conducted in each of the sealed chambers 33A and 33B. That is, the sealed chambers 33A and 33B may be arranged so as to have a construction which is capable of being connected to the gas bomb 34 and the gas exhaust pump 43 for conducting the gas exchanging step.

Incidentally, when the pressure on the gas supply side is set to a level such that no reverse gas flow occurs, as each of the electromagnetic valves 39A, 39B, 42A and 42B, a simple electromagnetic valve may be used, instead of the electromagnetic valve provided with the check valve.

Generally, in the projection exposure apparatus, in order to correct variations in image-forming characteristics, such as the magnification and distortion of the projection optical system, which are caused by a change in atmospheric pressure, and variations in these image-forming characteristics which are caused by irradiation of exposure light (so-called irradiation-dependent variations), sealed chambers are provided in the projection optical system at several sites where the above-mentioned variations in image-forming characteristics can be effectively corrected and pressures in these sealed chambers are actively changed. Alternatively, the above-mentioned variations in image-forming characteristics are corrected directly by controlling the positions of lenses in the projection optical system (so-called lens control). Especially, when the pressures in sealed chambers are controlled, bellows are generally used.

Therefore, in the above-mentioned embodiment of the present invention, a sealed chamber having a pressure which is capable of being controlled may be provided in the projection optical system PL so that the sealed chamber contains the gas in a space between lenses which are useful for effectively conducting correction of aberration in the projection optical system PL. In this case, the pressure in the sealed chamber may be controlled utilizing a pressure of the high-purity nitrogen gas, in stead of using bellows. By this arrangement, not only can variations in image-forming characteristics be corrected, but also deposition of haze substance on the surfaces of lenses in contact with the gas in the sealed chamber in the projection optical system PL can be prevented.

When the sealed chamber is provided in an optical path between the reticle and the wafer, the pressure of the inert gas contained in the sealed chamber may not be controlled, and as disclosed in, for example, U.S. Patent No. 5,117,255, optical characteristics (such as a focus position, a magnification, aberrations and telecentricity) and image-forming characteristics (such as image contrast) with respect to an image of the pattern on the reticle may be adjusted by moving at least one optical member in the projection optical system PL. In this case, an inert gas is selectively supplied to the sealed chamber so as to compensate for variations in light transmittance of the illumination optical system and/or the projection optical system PL, i.e., variations in light intensity of exposure light on the wafer. With respect to the optical integrator provided in the illumination optical system, the optical integrator is not limited to the fly-eye lens. A rod integrator may also be used as the optical integrator. The fly-eye lens and the rod integrator may be used in combination, as disclosed in U.S. Patent No. 4,918,583.

The present invention can be applied to not only a one-shot exposure type projection exposure apparatus, but also a scanning exposure type projection exposure apparatus, such as a step-and-scan type. The present invention can also be applied to an exposure apparatus of a proximity type or a contact type in which the projection optical system is not used. Thus, the present invention is not limited to the above-mentioned embodiment. Various modifications are possible without departing from the scope of the present invention as defined in the appended claims.

In the exposure apparatus of the present invention, a sealed chamber is provided in an optical path of exposure light in the illumination optical system. The gas in the sealed chamber is exchangeable. Therefore, for example, when the gas in the sealed chamber which is likely to generate haze substance is periodically ex-

changed with another gas, deposition of substance which lowers light transmittance and light reflectance of optical members, such as lenses, in the illumination optical system is unlikely to occur. Therefore, a lowering of illuminance of exposure light on the mask and a non-uniform distribution with respect to illuminance of exposure light can be suppressed.

Further, in the exposure apparatus of the present invention in which a pressure sensor is provided in the sealed chamber, the pressure in the sealed chamber can be maintained at a desired level.

In this instance, it is preferred that when the gas is in the sealed chamber is exchanged with a predetermined gas, the gas in the sealed chamber be exhausted through the gas exhausting system and the predetermined gas be supplied to the sealed chamber through the gas supplying system, while maintaining an amount of change in the pressure in the sealed chamber detected by the pressure sensor within a predetermined allowable range, from the viewpoint of suppressing a radical change in pressure in the sealed chamber. When a radical change in pressure in the sealed chamber is suppressed, stresses acting on optical members (such as lenses) in contact with the gas in the sealed chamber become low, so that an adverse effect on aberration of the optical members can be avoided.

Further, the present invention is especially advantageous when the illumination optical system comprises a light source adapted to emit exposure light, a shaping optical system adapted to shape the exposure light passing therethrough and an optical integrator adapted to enable the exposure light to have a uniform illuminance distribution after passing through the shaping optical system, and the sealed chamber is defined by two optical members constituting the shaping optical system, because it is possible to exchange the gas in a region where the illuminance of exposure light is high and therefore deposition of haze substance is likely to occur, and prevent occurrence of haze in that region.

The entire disclosure of Japanese Patent Application No. Hei 9-75355 filed on March 27, 1997 is incorporated herein by reference in its entirety.

Claims

1. An exposure apparatus for illuminating a pattern on a mask with exposure light passing through an illumination optical system, to thereby transfer said pattern on the mask to a substrate, comprising:

   a sealed chamber provided in an optical path of said exposure light in said illumination optical system,
   said sealed chamber containing a gas and shielded from a gas surrounding said sealed chamber in said illumination optical system; and
   a gas exchanging device adapted to exchange the gas in said sealed chamber with a predetermined gas.

2. The exposure apparatus according to claim 1, wherein said gas exchanging device comprises:

   a gas exhausting system adapted to exhaust the gas in said sealed chamber;
   a gas supplying system adapted to supply the predetermined gas to said sealed chamber;
   a pressure sensor provided in said sealed chamber to detect a pressure in said sealed chamber; and
   a control system adapted to control an operation of each of said gas exhausting system and said gas supplying system, based on said pressure in the sealed chamber detected by said pressure sensor, to thereby exchange the gas in said sealed chamber with the predetermined gas.

3. The exposure apparatus according to claim 2, wherein when the gas in said sealed chamber is exchanged with the predetermined gas, said control system enables said gas exhausting system to exhaust the gas in said sealed chamber and said gas supplying system to supply the predetermined gas to said sealed chamber, while maintaining an amount of change in said pressure in the sealed chamber detected by said pressure sensor within a predetermined allowable range.

4. The exposure apparatus according to claim 1, wherein said illumination optical system comprises:

   a light source adapted to emit exposure light;
   a shaping optical system adapted to shape said exposure light passing therethrough; and
   an optical integrator adapted to enable said exposure light to have a uniform illuminance distribution after passing through said shaping optical system, and said sealed chamber is defined by two optical members constituting said shaping optical system.

5. The exposure apparatus according to claim 1, wherein an inert gas is contained in said sealed chamber.

6. The exposure apparatus according to claim 1, wherein said sealed chamber is provided at a position at which said exposure light exhibits high illuminance.

7. The exposure apparatus according to claim 1, wherein said illumination optical system includes an input lens system and said sealed chamber is pro-

vided in said input lens system.

8. The exposure apparatus according to claim 1, further comprising a device adapted to maintain a temperature of the gas in said sealed chamber at a predetermined level.

9. The exposure apparatus according to claim 1, wherein the gas in said sealed chamber is exchanged periodically during idling of said exposure apparatus.

10. The exposure apparatus according to claim 1, wherein the gas in said sealed chamber is exchanged during assembly and adjustment of said exposure apparatus.

11. A method for conducting an exchange of gases in a sealed chamber provided in an exposure apparatus, comprising a gas exchanging step including:

a first sub-step of exhausting a gas in said sealed chamber from a gas exhaust side thereof, while said sealed chamber is closed on a gas supply side thereof; and
a second sub-step of supplying an inert gas to said sealed chamber from the gas supply side thereof, while said sealed chamber is closed on the gas exhaust side thereof,
wherein each of said first sub-step and said second sub-step is conducted in a substantially stationary state with respect to a pressure of the gas in said sealed chamber.

12. The method according to claim 11, wherein said exchange of gases in said sealed chamber is conducted periodically during idling of said exposure apparatus.

13. The method according to claim 11, wherein said exchange of gases in said sealed chamber is conducted during assembly and adjustment of said exposure apparatus.

14. The method according to claim 11, wherein in said first sub-step, a part of the gas in said sealed chamber is exhausted from the gas exhaust side of said sealed chamber and said gas exchanging step is conducted at least twice, and said method further comprises a step of measuring a total gas exchange time by counting the number of times said gas exchanging step is conducted.

15. The method according to claim 14, wherein said exchange of gases is conducted periodically during idling of said exposure apparatus and said method further comprises the steps of:

measuring an idling time of said exposure apparatus; and
comparing said idling time with said total gas exchange time, and when said total gas exchange time exceeds said idling time, a time for conducting said gas exchanging step at one time is reduced.

16. An exposure apparatus comprising:

an illumination optical system adapted to emit exposure light, said exposure light being adapted to illuminate a mask pattern to thereby transfer said mask pattern to a substrate;
a sealed chamber provided in said illumination optical system; and
a gas exchanging device adapted to exhaust a gas in said sealed chamber and supply an inert gas to said sealed chamber.

17. The exposure apparatus according to claim 16, wherein said illumination optical system includes an input lens system, said input lens system having at least one pair of lenses, and said sealed chamber is defined by said at least one pair of lenses.

18. The exposure apparatus according to claim 17, wherein said gas exchanging device comprises:

a gas exhausting system adapted to exhaust an impurity gas in said sealed chamber;
a gas supplying system adapted to supply an inert gas to said sealed chamber; and
a control system adapted to control said gas exhausting system and said gas supplying system so that a change in pressure in said sealed chamber is within a predetermined range.

19. The exposure apparatus according to claim 18, wherein said gas exhausting system includes:

a gas exhaust pipe adapted to exhaust said impurity gas from said sealed chamber;
an electromagnetic valve provided in said gas exhaust pipe to open and close said gas exhaust pipe, said electromagnetic valve being provided with a check valve; and
a gas exhaust pump connected to a gas exhaust side of said electromagnetic valve in the gas exhaust pipe,
wherein said gas supplying system includes:

a gas supply pipe adapted to supply said inert gas to said sealed chamber;
an electromagnetic valve provided in said gas supply pipe to open and close said gas supply pipe, said electromagnetic valve being provided with a check valve; and

a gas bomb connected to a gas supply side of said electromagnetic valve in the gas supply pipe, and
wherein said control system is adapted to control said electromagnetic valve in the gas exhaust pipe and said electromagnetic valve in the gas supply pipe.

20. A projection exposure apparatus for transferring a pattern on a mask to a photosensitive substrate, comprising:

a light source adapted to emit exposure light having a wavelength range in which a photosensitive substrate is sensitive to said exposure light;
an illumination optical system provided between said light source and said mask;
a projection optical system provided between said mask and said photosensitive substrate;
a sealed chamber containing a gas and provided in an optical path of said exposure light between said light source and said photosensitive substrate; and
a gas circulating device connected to said sealed chamber,
said gas circulating device being adapted to exhaust the gas contained in said sealed chamber to an outside thereof, to thereby compensate for variations in intensity of said exposure light on said photosensitive substrate.

21. The apparatus according to claim 20, wherein said sealed chamber is defined by at least two optical members provided in said illumination optical system.

22. The apparatus according to claim 20, wherein said gas circulating device is adapted to supply nitrogen or helium to said sealed chamber.

23. A projection exposure apparatus for transferring a pattern on a mask to a photosensitive substrate, comprising:

a light source adapted to emit exposure light having a wavelength range in which a photosensitive substrate is sensitive to said exposure light;
a sealed chamber provided in an optical path of said exposure light between said light source and said photosensitive substrate; and
a gas circulating device having a sensor and connected to said sealed chamber,
said sensor being adapted to detect and output information corresponding to a pressure in said sealed chamber, and
said gas circulating device being adapted to supply an inert gas to said sealed chamber in accordance with the information outputted from said sensor.

24. A method for transferring a pattern on a mask to a photosensitive substrate, comprising the steps of:

illuminating said mask with exposure light, to thereby transfer said pattern on the mask to a photosensitive substrate; and
exchanging an inert gas contained in a sealed chamber with another gas,
said sealed chamber being provided in an optical path of said exposure light,
to thereby compensate for variations in light transmittance and light reflectance of an optical member provided in said optical path of the exposure light.

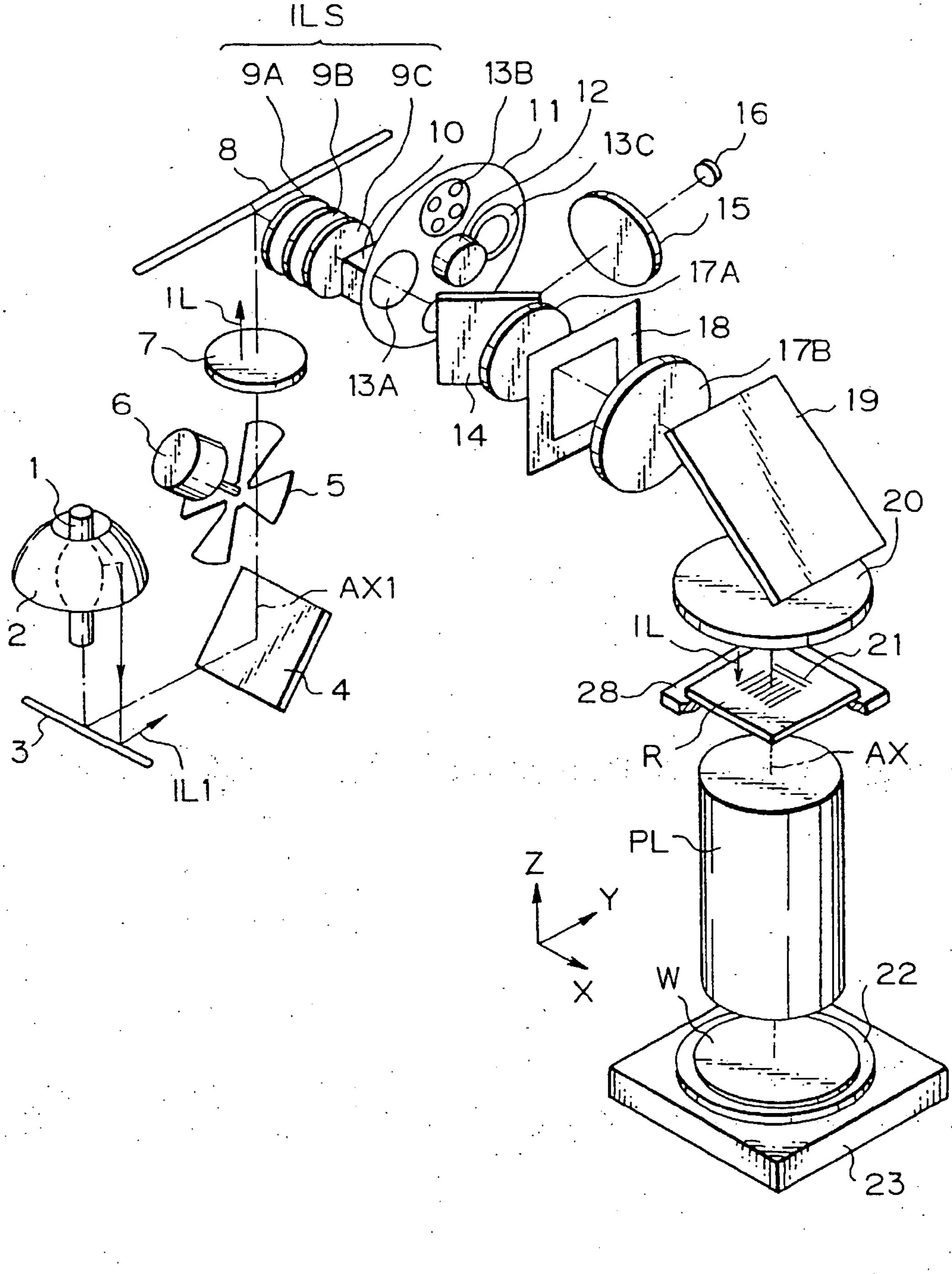
25. An exposure apparatus for transferring a pattern on a mask to a photosensitive substrate, comprising:

an optical system adapted to allow exposure light to enter,
said exposure light being adapted to be irradiated to a photosensitive substrate; and
a device adapted to supply a gas capable of suppressing attenuation of said exposure light to said optical system, according to a change in light transmittance of said optical system which occurs due to entrance of said exposure light.

26. A method for making an apparatus for transferring a pattern on a mask to a photosensitive substrate, comprising the steps of:

providing an optical system between a light source and a photosensitive substrate.
said light source being adapted to emit exposure light,
said exposure light being adapted to enter said optical system and irradiate said photosensitive substrate; and
providing a device adapted to supply a gas capable of suppressing attenuation of said exposure light to said optical system, according to a change in light transmittance of said optical system.

Fig. 1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14
19
6
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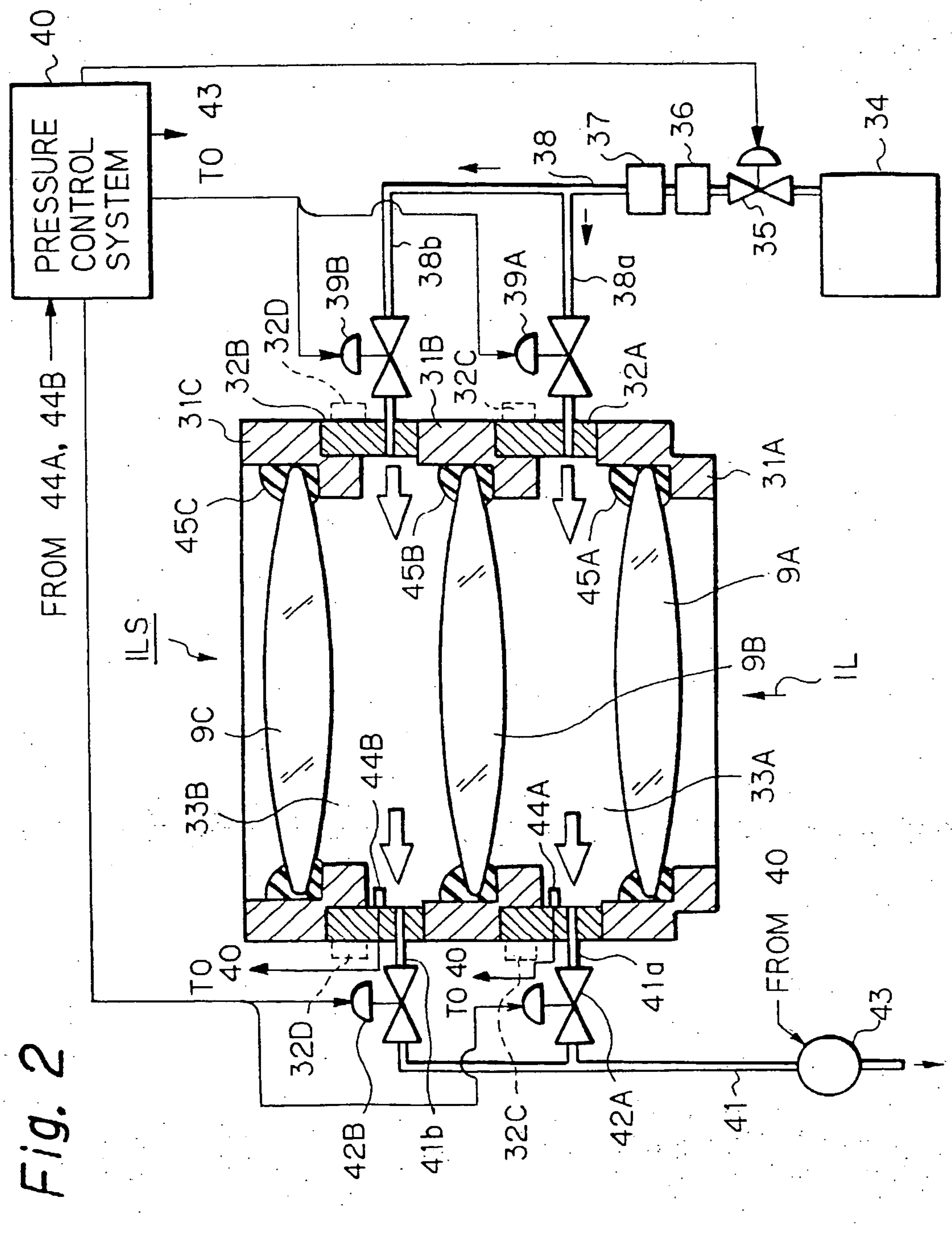
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TO 43
FROM 44A, 44B
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35
36
37
38
38a
38b
39A
39B
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32C
32D
31A
31B
31C
45A
45B
45C
9A
9B
9C
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42B
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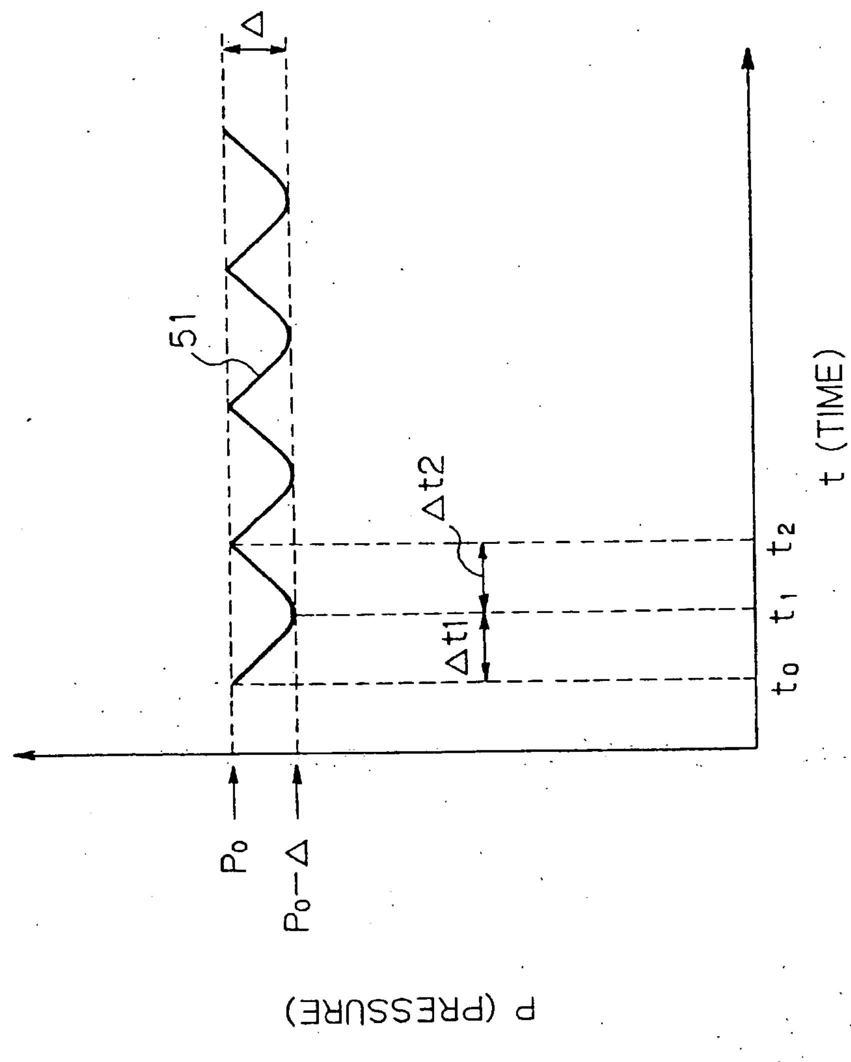
Fig. 2

Fig. 3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Δ
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$\Delta t1$
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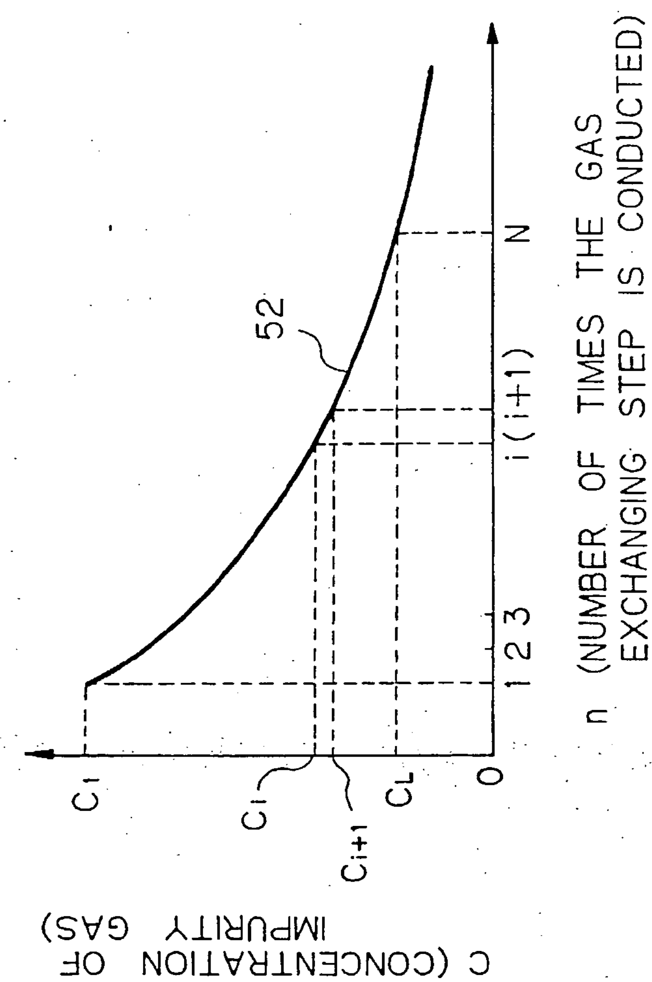
t_o
t_1
t_2
t (TIME)

Fig. 4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C (CONCENTRATION OF IMPURITY GAS)